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14. ABSTRACT

The main goal of this paper is to outline the steps required in inputting data when performing a trade-off study using TOSOM, paying special attention to the type and quantity of data required in such a study. A secondary and minor goal is to give some indication of how the output of a TOSOM study appears.

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DATA REQUIREMENTS FOR TOSOM (U)

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ABSTRACT (U)

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The Threat Oriented Survivability Optimization Model (TOSOM) was developed to provide a methodology to enable the Survivability Technology Area of the U.S. Army Tank-automotive and Armaments Command Research, Development and Engineering Center (TARDEC) to perform rapid turn around, first order analyses of survivability trade-offs in the design or modernization of military systems. TOSOM provides an easy to use capability to do analyses of alternative survivability suites. It contains embedded error trapping to insure that input data is mathematically consistent, as well as providing a means for easily assessing the results of a model run. TOSOM is a methodology, implemented in software, used for: selecting feasible solutions from a large number of possible responses, estimating the variety and magnitude of combat risk to a system, generating discussion and exchange of information, and enabling "what-if" analyses. Because of its ease of use, which is quick, reusable, and repeatable, TOSOM efficiently organizes the complex problem of designing survivability suites.

The main goal of this paper is to outline the steps required in inputting data when performing a trade-off study using TOSOM, paying especial attention to the type and quantity of data required in such a study. A secondary and minor goal is to give some indication of how the output of a TOSOM run appears. A detailed description of the organization and processing of the output data from TOSOM will be left to a future paper.

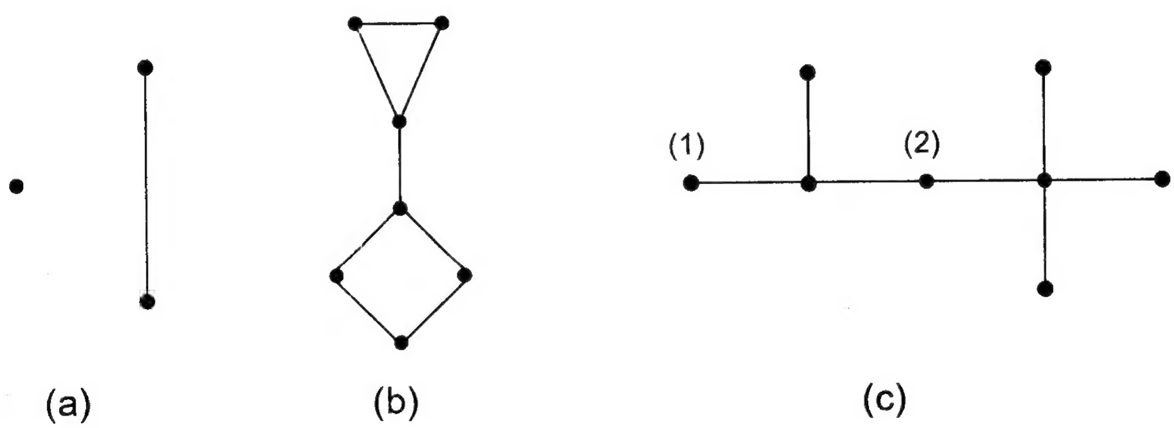
(U) Introduction

(U) TOSOM is a first-order, easy to use, model that permits the evaluation of combinations of countermeasure technologies in a postulated threat environment. The model is designed to evaluate a single platform in a given threat environment. In the sections below a detailed outline will be presented of the steps necessary in order to input the data required in performing a survivability study using the model. And in addition, an estimate of the amount of information required and of the type of information required will be provided. This quantity-of-information estimate will generally be a surprise to the causal user, since the volume of data required is an order of magnitude greater than the initial user of the model or viewer of its output believes.

(U) Since threats or rather the countering of threats is the heart of survivability and survivability trade-off analysis, threat trees are a sensible place to begin a discussion of the process of performing a TOSOM study. However, to explain threat trees, it's of value to have some minimal understanding of the mathematical concept of trees, and we spend considerable time elaborating the concept, since Schwarz, in [2], has stated that there is some confusion in the threat community as to what exactly is a threat tree.

(U) Trees

(U) Trees are a special type of graph. Graph theory, and trees as a special type of graph, is an extensive area of mathematics, see for example [1], though the concept is a simple one to understand. A graph is a collection of nodes (points) with the property that some of all the possible pairs of nodes are joined by an edge (line.). Examples of graphs are given in Figure 1 below.



(U) Figure 1: Examples of graphs

(U) In Figure 1, (a) has 3 nodes and 1 edge, (b) has 7 nodes and 8 edges, and (c) has 8 nodes and 7 edges. In an obvious sense, (a) is an example of a non-connected graph, while (b) and (c) are examples of connected graphs.

(U) A tree is a connected graph with no loops. As just noted, (b) and (c) in Figure 1 are connected. However, (b) has a loop and is therefore not a tree. (c) is a tree.

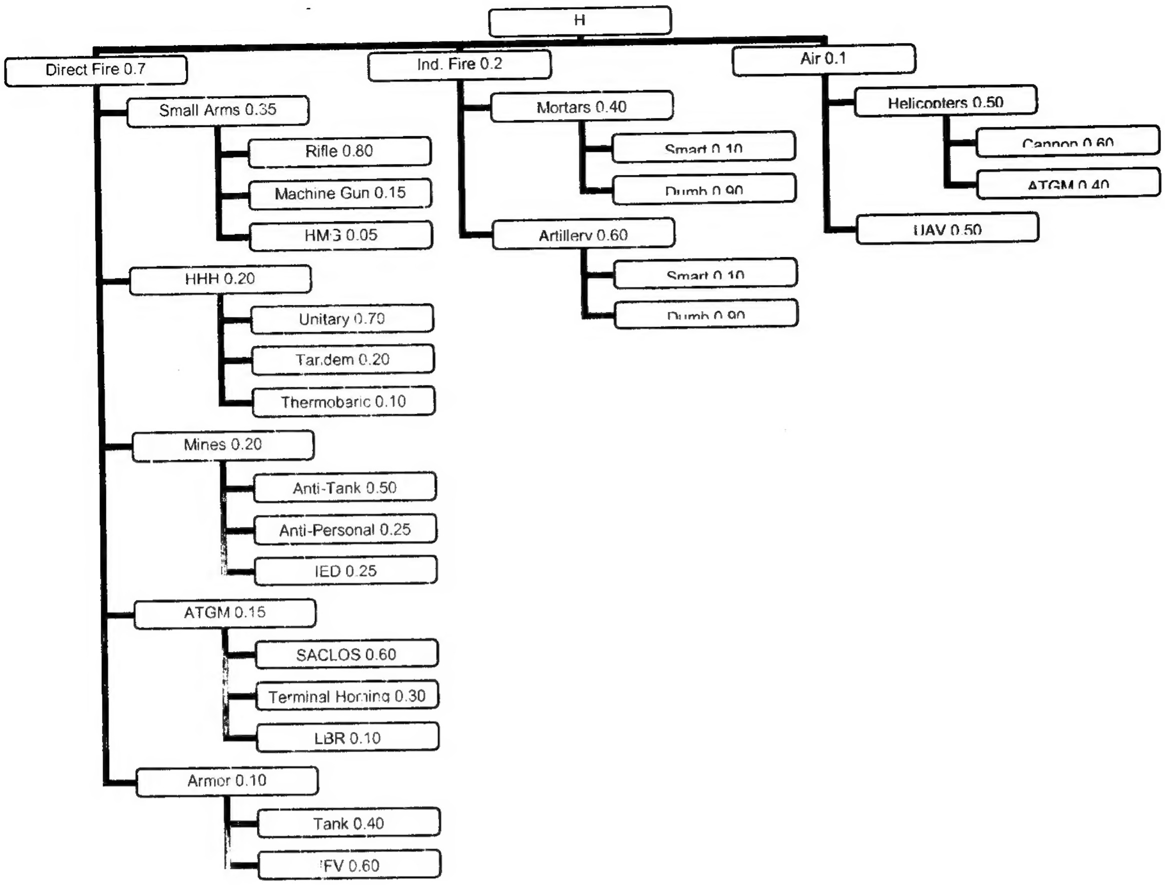
(U) A tree structure is a tree with the nodes labeled in a particular fashion. A node of the tree is selected and called the Level 0 node. The Level 0 node branches (think of an upside down tree) into one or more Level 1 nodes. Each Level 1 node can be either a terminal node (that is, it does not branch), or can branch into several Level 2 nodes. This process continues until at some level, every node is a terminal node.

(U) A given tree can have several distinct tree structures associated with it. For example, in Figure 1(c), if (1) is chosen as the Level 0 node, then there is 1 Level 1 node; 2 level 2 nodes, 1 of which is terminal; 1 Level 3 node; and 3 Level 4 nodes, all 3 of which are terminal nodes. But if (2) in Figure 1(c) is chosen as the Level 0 node, then there are 2 Level 1 nodes; and 5 Level 2 nodes, all of which are terminal. Thus, a tree structure depends upon the underlying tree, and upon the node chosen to be the Level 0 node.

(U) An aside is worth noting before proceeding with TOSOM. That is, mathematically, trees with infinitely long branches occur, but tree structures as defined above restrict branches to a finite, though variable, length. That is, every branch of the tree starts at the unique Level 0 node, and after a finite number of branches, ends at a Level k (for some positive integer k) terminal node.

(U) A threat tree is a particular type of tree structure. In a threat tree, each branch is assigned a probability, with the constraint that the sum of the probabilities of all braches leaving each node must be 1. The actual threats in a threat tree are those nodes that have no branches leaving them; that is, the actual threats are the terminal nodes in the threat tree.

(U) A TOSOM threat tree has two additional restrictions. First, each node can have at most five branches leaving it. Thus, there are at most 5 level 1 nodes, at most 5x5 =25 level 2 nodes, at most 5x5x5 =125 level 3 nodes, etc. The second restriction is that there are no nodes deeper than level 5. A typical TOSOM threat tree is shown is Figure 2.



(U) Figure 2: A typical TOSOM threat tree

(U) Structure of a TOSOM Study

(U) The first step in executing a TOSOM study is to create a threat tree. TOSOM threat trees can vary widely, from a single threat (unlikely, but possible) to a maximum of 5^5 = 3,125 threats (possible, but also unlikely). A typical TOSOM threat tree will have around 30 threats (terminal nodes) and around 50 branches providing a unique branching path to each threat from the level 0 node. As noted above, each branch must have a probability assigned to it, with the sum of the branch probabilities leaving each node summing to 1. Thus, a typical TOSOM threat tree will require 50 data points for its creation.

(U) Once the distribution of the threat has been specified by the branch probabilities, the next step is to specify the probability of acquisition, the probability of hit, and the probability of kill for each threat. In the typical threat tree offered above, this will require 3x30 =90 data points.

(U) At this point in the study sequence it's time to consider the particular countermeasures available for incorporation onto the platform. However, before the countermeasures are specified, it's necessary to specify the burdens that are of importance to the study. Burdens are various properties associated with each countermeasure. They are specified by the study manager, but will generally include items such as cost of the countermeasure, weight of the countermeasure, space required by the countermeasure, and other factors the study manager deems important. At times, depending upon the study, the space claim burden may be broken into two burdens: volume under armor, and volume not under armor. Also, at times, power consumption may be of importance as a burden; at others, peak power consumption. Each burden requires the specification of a maximum value. More about the role these maximum values play when the model's combinations of countermeasures is discussed.

(U) The study sequence now requires the specification of the countermeasure technologies that are to be considered. These countermeasures will generally include armor packages of various types, signature reduction techniques, jammers, and any of various other devices that the design engineer might conceive. Each countermeasure will require a value for each burden, giving its contribution to that burden. Also, each countermeasure will need to specify its effectiveness against each threat. Thus, in a typical study with 30 threats and 4 burdens, each countermeasure will need to provide 34 data points. If it's noted also that a typical study might have 8 countermeasures, then the specification of the countermeasures in that study will require 8x34 =272 data points. TOSOM is a simple model, but like all models, it is data intensive.

(U) An additional point regarding the input of countermeasures into the TOSOM model requires a remark. Countermeasures can be grouped. For example, if there are three types of armor under consideration as potential countermeasures, but at most one of them can be installed on the platform being studied, then the three armor countermeasures would be grouped. In a grouped collection of countermeasures, TOSOM in determining possible countermeasure suites would choose at most one countermeasure from each grouped collection of countermeasures.

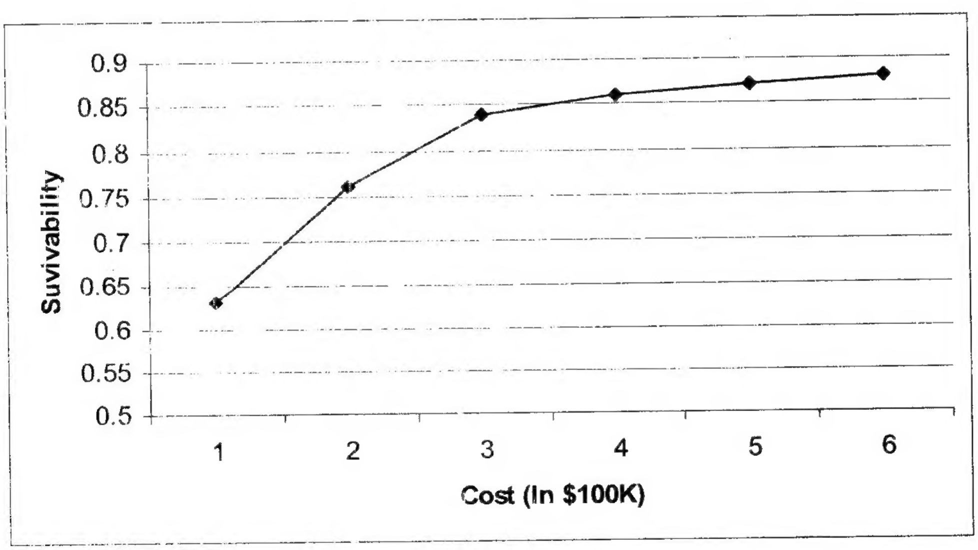
(U) For example, if A1 and A2 are two armor countermeasures which are grouped, and S1 and S2 are two signature countermeasures which are grouped, and J is a jammer, then TOSOM would generate at most (more about this below) 18 countermeasure suites, not the 32 suites normally expected from 5 individual countermeasures.

(U) Normally, if there are k countermeasures in a TOSOM study, there will be at most 2k countermeasure suites, including the baseline (that is, the platform with no countermeasures). There are two circumstances that can reduce the number of countermeasure suites. The first, as noted above, is the grouping of some of the countermeasures. The second has to do with burdens, and an example with make the circumstance and the methodology clear.

(U) `Suppose, for example, that cost is a burden. Recall that each burden is assigned a maximum value, and suppose in this example that the maximum value for cost is $500,000.

Suppose that A is an armor package with a cost of $100,000. Suppose that P is an active protection package with a cost of $300,000. Finally, suppose that S is a signature reduction countermeasure with a cost of $250,000. As noted above, with 3 countermeasures, 8 countermeasure suites is the maximum number possible, but in this instance TOSOM will only produce 6 countermeasure suites. The suite consisting of P and S will be rejected because its total cost, $550,000, exceeds the cost burden limit. Likewise, the suite consisting of all three countermeasures will be rejected. The other 6 countermeasure suites will all be considered, since each has a cost below the $500,000 maximum cost. For reference, those 6 suites are: the baseline, no cost; the armor package A with a cost of $100,000; the active protection package P with a cost of $300,000; the signature reduction package S with a $250,000 cost; the suite consisting of A and P with a cost of $400,000; and finally, the suite consisting of A and S with a cost of $350,000.

(U) For each countermeasure suite (the baseline will always be one of them) that TOSOM generates TOSOM will also produce an estimate of the platform's survivability when it's equipped with that suite. For details on how these survivability values are computed, please see [3]. These survivability values can be used by the decision maker in a variety of ways. For example, the survivability of various suites can be compared to that of the baseline platform and these survivabilities can be related to any of the burden values, but with cost almost always being the one of primary interest. The comparison between cost and survivability provided by a typical TOSOM study is frequently displayed as in Figure 3. This provides the decision maker with a quick way to estimate the marginal utility of increasing survivability as a function of increasing cost.



(U) Figure 3: A final result of a TOSOM study

(U) Conclusion

(U) How many data points are required for a TOSOM study? Combining what has been laid out above the question can now be answered. This estimate will depend upon four quantities, only three of which can be know exactly. The three that can be know exactly are: the number of threats, T; the number of burdens, B; and the number of countermeasures, C. The quantity that can't be known exactly is the number of branches in the threat tree, since this number in not a direct dependence upon T but is also affected by the structure of the tree. However, it will not be an egregious error to assume that the number of branches is double the number of threats. On that assumption, there are 2xT branch probabilities. That is, 2xT encounter probabilities will be required. Since each threat requires probabilities of acquisition, hit, and kill, 3xT data points will be required to specify threat lethality. B data points will be required to specify the maximum values for the burdens. Since each countermeasure, C, must state its contribution to each burden, B, CxB data points will be needed. And finally, since each countermeasure, C, must specify its effectiveness against each threat, T, CxT data points will be required.

(U) In total, if there are T threats, B burdens, and C countermeasures in a TOSOM study, then approximately

$$(C+5)xT+(C+1)xB$$

data points will be required. For example, a typical TOSOM study might have 30 threats, 4 burdens, and 8 countermeasures. Thus, the study would require the specification of (8 +5)x30 +(8 +1)x4 =426 data points.

(U) <u>Summary</u>

(U) The step-by-step data requirements for a TOSOM study have been explained. A reference to the methodology TOSOM uses in its calculation of survivability has been provided, [3], and a forthcoming paper will discuss how the output of TOSOM is analyzed and presented, a hint of which was provided in Figure 3 above.

(U) <u>References</u>

(U) [1] Fred S. Roberts, Applied Combinatorics, Prentice-Hall, Englewood Cliffs, New Jersey, 1984, especially Chapter 3.

(U) [2] Fred Schwarz, Private communication.

(U) [3] Dave Fredrick, Daniel Hicks, Jack Reed, and William Jackson, TOSOM Anatomy with Examples, Proceedings of the Seventh Annual Ground Target Modeling and Validation Conference, August 1996, Michigan Technological University, pages 1-10.